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# U.S. PATENT APPLICATION


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*Invention:* RADIO FREQUENCY DIPLEXER


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# SPECIFICATION

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4. That I believe that all statements made herein of my own knowledge are true and that all statements made on information and belief are true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the patent application in the United States of America or any patent issuing thereon.

For and on behalf of RWS Group plc

The 5th day of September 2003

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Radio frequency diplexer

The invention relates to a radio frequency diplexer in the form of interconnected radio frequency filters according to the precharacterising clause of Claim 1.

In radio systems, for example in the mobile radio field, it is often desirable to use only one common antenna for the transmission signals and the received signals. The transmission signals and received signals in this case use different frequency bands. The antenna which is used must be suitable for transmitting and receiving both frequency bands. Suitable frequency filtering is required to separate the transmission signals and received signals, ensuring on the one hand that the transmission signals are passed on from the transmitter only to the antenna (not in the direction of the receiver), and on the other hand that the received signals are passed on from the antenna only to the receiver.

A pair of radio frequency filters may be used for this purpose, both of which pass a specific frequency band, namely the respectively desired frequency band (band pass filters). However, it is also possible to use a pair of radio frequency filters which block a specific frequency band, namely the respectively undesired frequency band. These are referred to as bandstop filters. It is also possible to use a pair of radio frequency filters, comprising a first filter which passes frequencies below a frequency that is between the transmission band and the reception band, and blocks the bands above this (low-pass filter), and a second filter, which blocks frequencies below this frequency that is between the transmission band and the reception band, and passes frequencies above this. This is what is referred to as a high-pass

filter. Further combinations of the stated filter types may be used.

US 6,392,506 B2 discloses a duplex filter in which radio frequency filters are interconnected and in which the inner conductor of a common coaxial transmission/reception connecting socket is connected via two conductor loops to in each case one closest resonator chamber in the transmission and receiving filters. In this case, a vertically projecting inner conductor is provided internally in each resonator chamber, with the chamber wall which bounds the resonator chamber radially on the outside being used as an outer conductor. In the corresponding already known solution, the area which is enclosed by the wire loop including the current feedback path via the inner wall of the resonator cavity to the outer conductor of the connecting socket (inductance) determines the strength of the signal injection in the respective filter path. The input can be tuned by mechanical deformation or bending of the wire loop.

In the capacitive case, the inner conductor of the common transmission/receiving connecting socket is split into two conductor pieces, which each end in flat metal pieces. In this case, the strength of the signal input is governed by the size and shape of these metal surfaces, and by their distance from the inner conductor of the respective resonator (the capacitance resulting from this). The input can in this case likewise be tuned by mechanical deformation or bending of these metal surfaces, and by changing the distance to the respective inner conductor of the resonator filter.

Both variants have the disadvantage that the tuning process can be carried out only by purely reproducible mechanical manipulations (bending or deformation), and that the tuning of the input to one filter path also influences the electrical behavior of the respective

other filter path, and vice versa, so that the two input devices must generally be varied alternately two or more times during the tuning process.

This disadvantage is avoided according to Figures 3 and 4 in the prior publication US 6,392,506 B2 which has been mentioned, in that there is now only one capacitive input from the inner conductor of a common connecting socket to one resonator which is additionally provided for the two filter paths and may be referred to as a so-called "central resonator". This provides coupling in the conventional manner via openings in the separating walls to in each case one resonator in the transmission filter path and one resonator in the receiving filter path.

However, in this case as well, it must be regarded as being disadvantageous that the central resonator which is acquired in addition to the resonators in the filter path requires additional space and also results in additional costs, even though it does not significantly contribute to the frequency selectivity of the filter paths.

In contrast, the object of the present invention is to provide for the interconnection of radio frequency filters, in order to produce a frequency diplexer, in a better way than the generic prior art.

According to the invention, the object is achieved by the features specified in Claim 1. Advantageous refinements of the invention are specified in the dependent claims.

In a first variant according to the invention, the two radio frequency filter paths are interconnected by means of an inductive or capacitive input to one resonator in a pair of resonators which are strongly coupled to one another (interconnection resonator pair). This avoids the disadvantages explained in the

prior art. This means that, in contrast to the prior art, there is no longer any need to carry out a tuning process at the two points between which there is an interaction.

Furthermore, the resonator pair which are strongly coupled to one another contribute to selection of the two filter paths, to be precise in a similar manner to that if one of the two resonators were in each case permanently associated with one of the filter paths. This avoids the central resonator which is required in the prior art, causes additional costs, and furthermore, also requires even more space.

The coupling between the interconnection resonator pair and the filter paths in the frequency diplexers can in this case be carried out differently, namely,

- according to the invention, it is possible for the two filter paths, namely the filter path for the transmission signals and the filter path for the received signals, to be coupled to the second resonator in the resonator pair which are strongly coupled to one another, which is not used for the input; or
- both filter paths can be connected to the first resonator in the strongly coupled resonator pair, which is also used for the input from the inner conductor of a coaxial radio connection.

A further advantage of the present invention is justified by the fact that advantageous, space-saving geometric arrangements of the resonator chambers are possible for certain numbers of resonators, and are thus not possible for other forms of interconnection. For the purposes of the present invention, it is thus possible, for example, to provide a frequency diplexer with a total of six resonators, which are arranged in two rows of three each, and in which all three connecting sockets, for the transmitter, for the

receiver and for a common port or a common connecting socket, that is to say in general a common transmitting/receiving connecting socket, for example for connection of an antenna or for the input/output of a common signal path, are located on the same side of the housing. In other words, the present invention makes it possible to provide symmetrical, compact overall geometries.

Furthermore, one preferred embodiment of the invention allows particularly strong coupling by considerably shortening the distance between the inner conductors of the relevant resonators.

The radio frequency diplexer according to the invention is preferably constructed such that at least one resonator, preferably two or more resonators, and preferably all of the resonators, has or have a coaxial configuration. The radio frequency diplexer can likewise be constructed with one or more or all of the resonators using dielectric resonators, for example ceramic resonators. Finally, however, it is likewise possible to construct the radio frequency diplexer such that at least one resonator, but preferably two or more resonators or even all of the resonators, uses or use stripline technology. In other words, all methods, even those which are only imaginable, may be used, in which it is possible to appropriately implement the explained principles.

The invention will be explained in the following text for various exemplary embodiments and with reference to the attached drawings, in which, in detail:

Figure 1: shows a schematic horizontal cross section illustration through one preferred embodiment of a diplexer according to the invention with radio frequency filters interconnected according to the present invention;

Figure 2: shows a cross section illustration along the lines II-II in Figure 1;

Figure 3: shows a cross section illustration along the line III-III in Figure 1;

Figure 4: shows an exemplary embodiment, modified from that shown in Figure 1, of a further embodiment according to the invention; and

Figure 5 shows an illustration of the resonance response of two supercritically coupled resonators.

Figure 1 shows a schematic horizontal cross section through one preferred embodiment according to the invention of a diplexer with interconnected radio frequency bandpass filters.

For this purpose, the exemplary embodiment shown in Figure 1 has six individual circuit radio frequency filters 1, with a coaxial configuration, that is to say six resonators. The configuration of the resonators 1 under discussion is in principle known from EP 1 169 747 B1, to whose complete scope and full content the present application refers. It is also possible to see from this that a single circuit RF filter or single resonator 1 with coaxial configuration in principle comprises an electrically conductive outer conductor 3, an inner conductor 4 which is arranged concentrically or coaxially with respect to it, and a base 5, via which the electrically conductive outer conductor 3 and the electrically inner conductor 4 are electrically connected to one another.

The single resonator can be closed at the top via a cover 7 that can be fitted (see also Figure 2), that is to say via an electrically conductive cover 7, with the

inner conductor ending at a distance underneath the cover 7. A specific setting to one resonator frequency can be provided by specific adjustment mechanisms, for example by axial adjustment of the inner conductor or by axial adjustment of a tuning element which is provided in the cover, as shown in Figure 2.

In the illustrated exemplary embodiment shown in Figures 1 and 2, one of the six coaxial radio frequency resonators that are shown in Figure 1 is shown with a rather square base surface or base 5, whose cavity is bounded by metallic walls. The corners are rather rounded, which has manufacturing advantages (particularly if the resonator cavity is milled from a solid metal block). The metallic inner conductor, which is generally in the form of a circular cylinder and whose length is somewhat less than one quarter of the wavelength of the resonant frequency, normally ends at a distance of generally a few millimetres under the cover. A tuning element 9 is provided in the exemplary embodiment shown in Figure 2, and is in the form of a cylindrical metal pin which is screwed in and out to different extents from the cover and in the process can engage to a different extent in a recess 4′ which is incorporated at the upper end of the inner conductor 4. This makes it possible to vary the resonant frequency.

Two or more of these single resonators 1 are then accommodated in a common housing 11, with the side walls of the cavities 14 which normally separate the single resonators from one another being provided in some cases with apertures 15, which produce the electromagnetic signal path.

Furthermore, three connecting sockets are provided in the illustrated exemplary embodiment, at the same distance from one another on one side 19 of the housing 11, that is to say in the illustrated exemplary embodiment 3 coaxial connecting sockets 21, 22 and 23.

The respectively associated inner conductors 31, 32 and 33 for the three connecting sockets 21 to 23 are each lengthened by a few millimetres into the respective resonator chambers 41, 42 and 43 which are adjacent to the housing sidewall 19, and each end in a conductive flat element, in the illustrated exemplary embodiment in the form of an electrically conductive disk 31', 32', or 33' respectively.

Figure 1 also shows that, for example, a transmitter T is connected to the connecting socket 21, a common signal path A which is used for the input and output is connected to the central connection 22, and a receiver R is connected to the third connection 23. In other words, transmission signals are fed in from the transmitter via the signal path as shown by the illustrated arrows 25 via the duplex filter formed in this way and having the radio frequency bandpass filters into the common signal path A, for example to an antenna, whereas, in contrast, signals which are received via the common signal path A are fed into the receiver R from the central connecting socket, as shown by the arrows 26.

The capacitance which is formed between the central disk element or other flat metal piece 32' and the adjacent resonator inner conductor 42a of the input resonator R42 provides the input for the electrical field from the common signal path A or from the common connecting socket 22 to the resonator chamber 42, and vice versa.

In the illustrated exemplary embodiment, strong coupling is provided via the connecting opening 45 between this first resonator chamber 42, which produces a connection to the antenna A, and an adjacent, second resonator chamber 42', which is connected to it.

In addition, the coupling which is required for this type of interconnection between the two resonator chambers 42 and 42′ can be adjusted as follows. It is obvious from the exemplary embodiments which have been explained that, with respect to the signal path, the distance between two adjacent inner conductors 42′a and 43′a as well as 43′a and 43a as well as the distance between the inner conductors 42′a and 41′a as well as 41′a and 41a is in each case approximately the same. As is shown in Figure 1 and Figure 2, it is possible, in order to adjust the coupling, to design the distance between the two inner conductors, which do not belong either to the sole transmission path nor to the sole reception path, that is to say the distance between the inner conductors 42a, 42′a of the resonators which are strongly coupled to one another, to be shorter than the distance between the remaining inner conductors with respect to their signal path.

The strong coupling which has been explained, and which is also referred to as being supercritical, means that the two resonators R42 and R42′ which, considered in their own right, each have a resonance point in the frequency range between the transmission band and the reception band and are tuned to this, oscillate at two so-called coupling resonant frequencies which are not the same as this and are not the same as one another, in the coupled state.

The separation (that is to say frequency difference) between these two coupling resonant frequencies is normally referred to as the coupling bandwidth.

In the case of resonators which are coupled to one another and are part of the same filter with the same filter path (transmission path or reception path) in a duplex filter, this coupling bandwidth is generally somewhat narrower than the bandwidth of the filter or filter path. In other words, this coupling bandwidth is

typically in the range between 50% and 100% of the bandwidth of the filter or of the filter path.

In the case of the strongly coupled interconnection resonator pair, this coupling bandwidth is in contrast wider than the respective bandwidth of the filter paths which are interconnected to form a duplex filter.

The graph illustrated in Figure 5 will be used, by way of example, to show the transmission response of a circuit (that is to say of a filter) comprising two super critically coupled resonators. In this case, the frequency is plotted on the x-axis, and the scatter parameter S21 is plotted on the y-axis.

In this case, strong coupling is equivalent to a wide coupling bandwidth.

The frequencies of the resonators are tuned by using the tuning elements 9 which can be screwed in and out in the respective filter, as has already been explained with reference to Figure 2, or as is described for an embodiment that differs from this in the prior publication EP 1 169 747. Further modifications of signal resonators which can be tuned are also possible.

The filter circuits of the transmission path, comprising the resonator chambers R41′ and R41 are coupled through the further opening 48 between the second resonator chamber R42′ of the interconnection resonator pair R42, R42′ and their adjacent resonator chamber R41′ to the second resonator R42′, which is not used as the input for the antenna A, in the interconnection resonator pair R42, R42′. The two resonator chambers R41′ and R41 in the transmission path are likewise coupled to one another through an opening 48′ in the single resonator wall. The transmission signals are input via the electrically conductive flat element 31′ that is provided here.

A reception path is formed in a corresponding manner. In this case as well, a coupling connection is produced via an opening 49 from the second resonator R42′ in the interconnection resonator pair to the resonator R43′ and via a further opening 49′ to the resonator R43, into whose resonator space the electrically conductive flat element 33′ projects. The received signal which is received by the antenna A can be fed via this into the receiver R, that is to say it can be passed to the receiver R.

The resonators R41 and R41′ are in this case tuned to frequencies in the transmission band, and the resonators R43, R43′ are tuned to frequencies in the reception band.

The interconnection is balanced via a correspondingly balanced version of the coupling between the resonator chambers R42′ and R41′ on the one hand and the coupling between the resonator chambers R42′ and R43′ on the other hand. Significant influencing variables are in this case the size, the position and the shape of the coupling openings in the resonator separating walls, and the distances between the axes of the respective inner conductors 42′a and 41′a, as well as 42′a and 43′a. All of these dimensions can be produced by milling, in a manner which can be reproduced mechanically to a satisfactory degree.

The following text refers to a modified exemplary embodiment as shown in Figure 4.

This exemplary embodiment has a largely similar configuration. The difference from the exemplary embodiment shown in Figure 1 is that the central antenna connection, that is to say the central antenna socket 22, is provided on the opposite side 19′ of the housing, in contrast to the two other coaxial

connecting sockets 21, and 23. Thus, in contrast to the exemplary embodiment shown in Figure 1, provision is made in the exemplary embodiment shown in Figure 4 for the filter circuits R41 and R41' in the transmission path to be coupled to the first resonator R42, which is used as the input to the connected common signal path A, of the interconnection resonator pair R42, R42'. In a corresponding manner, the receiver path with the resonator chambers R43 and R43' is likewise coupled to the first resonator chamber R42, which is used as the input.

Since, in the exemplary embodiment shown in Figure 4, the connection 22 is provided opposite the two other connections 21 and 23, that is to say the first resonator chamber 42 which directly is connected to the antenna connection 22, and hence the associated resonator R42, are arranged on the opposite side 19' of the housing.